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Dielectric and Mechanical Characteristics of Oil Palm Mesocarp Fiber- Kondagogu Gum Composites

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Abstract

Background / Objectives: Currently, synthetic materials are being replaced by natural fiber composites, due to their adverse effects on environment. This paper introduces Gum Kondagogu (Cochlospermum Gossypium), a novel matrix which is extracted from the tree of Kondagogu. In the current investigation, the impacts of alkali treatment on the Dielectric and Mechanical characteristics of natural composites were studied to explore their usability in Microelectronics and Integrated circuits.

Methods / Statistical Analysis: In this article, chopped oil palm mesocarp fiber is reinforced into the gum kondagogu to prepare composites using the hand-layup technique.

Findings: The ratios of matrix and reinforcement composites were significantly influenced by the mechanical characteristics of strength parameters Impact, Flexural and Tensile characteristics and evaluated by Dielectric characteristics of various parameters such as Dielectric loss(e''), Dielectric constant (e'), and Dissipation factor (D) of pure gum and composites with varying fiber content percentages (05%, 10% and 15%) of oil palm mesocarp fiber in a range frequency is 100Hz to 1MHz, at room temperature.

Applications / Improvements: Alkali treated composites have shown better results than untreated ones in terms of dielectric loss and dielectric constant. As the frequency rises, the dissipation factor and dielectric loss decrease.

Keywords: Dielectric properties, Mechanical properties, Gum Kondagogu, Oil palm mesocarp fiber, biocomposites.

1. Introduction

With a wide range of uses, a huge selection of items, and top-notch qualities like strong strength, easy to manufacture, low cost etc. make the polymers and polymer composites make up most of the products in the day-to-day life ranging from small band aids to MRI machines, from toys to aero planes and many more but unfortunately, due to their non-biodegradable nature they are becoming a potential threat to environment [1]. To overcome these problems, more research is being done with

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natural fibers reinforced with plant resins like Soya protein [2], wheat protein [3], Kondagogu gum [4], gum Karaya [5], Guar gum [6], tamarind seed gum [7], Catechu Resin [8], Corn Starch [9] etc.,

which are further reinforced with various natural fibers like hemp [10], jute [11], kenaf [12], coir [13], Tamarindus indica [14], oil palm [15], banana [16] and bamboo [17] etc. to enhance their properties further. Natural composites have demonstrated to be suitable reinforcement materials for composites with excellent mechanical, electrical, thermal, and acoustic properties through the many experiments and studies carried out. With various environmental advantages like nearly never-ending supply chain and biodegradability, they have gained significant importance in various applications like the automotive industry, electrical industry, etc [18-20]. Natural fibres having dielectric properties can be used in capacitors, microelectronic components, and communication and energy storage appliances. Dielectric materials are used in various electric appliances [21]. Low-dielectric and high-dielectric materials are the two most frequent types of dielectric materials based on dielectric constant values. Low dielectric materials, which have a low dielectric constant (low K), are preferred in microelectronics because they allow for higher device speeds, lower power consumption, lower heat dissipation, and less interline chatter [22,23].

Researchers found a way to make dielectric materials using biopolymers, which is similar to making biodegradable printed circuit boards (PCBs) and other electronic composites, to minimise the environmental pollution produced by synthetic polymers and e-waste [3]. Dielectric applications are also being researched using various fibres and biopolymers [24,25]. The dielectric characteristics of a material are also impacted by environmental factors such as materials, temperature, and moisture content, the presence of air, voids, and frequency of testing.

Various gums which are found in the forests are extracted and are being used in the preparation of composites. Cochlospermum Gossypium also known as Gum Kondagogu, a small to medium sized soft-wooded tree mostly found in the states of Telangana and Andhra Pradesh, is used to develop the composites. The Gum kondagogu is used as a binder or a matrix, and fibers as the reinforcement. Composites are prepared by adding various additives in minute quantities to improve the ductile nature and binding properties. Gum Kondagogu is considered a polysaccharide which has a high molecular weight and is composed of monosaccharide units, uronic acids, proteins, and fibers [26].

Natural fibers are a type of fibers which is obtained from plants and animals, these natural fibres are generated from a variety of plants and animals that we encounter every day, ranging from animals to fruits and vegetables we use regularly and also various by-products of various crops. There are various different fibers available like palmyra, oil palm, coir, banana, kenaf, jute, tamarind, cotton, bamboo, etc. that are being used to prepare natural composites [27]. Oil palm is one of the four most important vegetable oils that are being used worldwide. It consists mainly of cellulose, hemicellulose, holocellulose, lignin, and ash in higher quantities. Oil palm fiber is being used to prepare the natural composite which is being widely cultivated in the southern parts of India. Oil palm fruit branches, which are a byproduct of oil palm mills, can be used to recover oil palm fibre.

The mechanical and dielectric properties of banana fiber/wheat gluten composites were investigated by H.B. Bhuvaneshwari et al. [28]. Banana fibre and wheat gluten are mixed in various ratios ranging from 70/30 to 50/50 to make the composites. The composites were developed with a wide range of dielectric properties, which can serve as replacements for traditional dielectric materials and be employed in a variety of electronic applications. SC Mishra and H Aireddy [29] investigated the dielectric properties, AC conductivity, and resistivity of pure epoxy composites with frequency range on 100Hz to 1MHz. The dielectric properties of the composite decreased as the frequency increased.

In their study of the dielectric properties of fiber-reinforced epoxy composites, Chand and Jain [30] found that while the A.C conductivity of the composites increased, the dielectric constant tan d of the

composites decreased as the frequency increased. At the epoxy composite transition temperature, some anomalous behaviours of the composites were found.

Maya Jacob et al. [31] looked at the dielectric properties of sisal-oil palm composites bonded with natural rubber. The dielectric constant grew as the fibre loading increased; however, the dielectric constant decreased as the orientation polarisation decreased due to chemical treatment of the fibre, according to the authors.

The aim of the research is to build mechanical and dielectric characteristics of biodegradable composites using Gum Kondagogu and oil palm mesocarp fiber which can be suitable alternatives to replace the polymers and polymer composites which are being used as dielectric materials like porcelain, ceramics, glass, sulfer hexafluoride etc. and find applications in various fields like Microelectronics and Integrated circuits as capacitors and semiconductors etc.

2. Materials and Methods

2.1. Raw Materials

Gum Kondagogu (grade 1) was acquired from the Girijana Cooperative Society, Telangana. The oil palm mesocarp fiber is purchased from 3f oil palm industries. Glycerol (98% purified), glutaraldehyde (25%), NaOH, HCL, distilled water are purchased from sri Aditya chemicals, hanamkonda.

2.2. Surface treatment of Oil Palm Mesocarp fiber

Palm Oil Retting is a process used to obtain mesocarp fibre from the oil palm's empty fruit branch [32]. Due to the environmental pollution caused by chemical and steam retting, mechanical retting processing is mostly used to crush the fruit branches, fruit shells, and husks to extract the oil palm fibre, which is then sieved to remove impurities before being loosened, dry cleaned and cut into the various lengths. The fibres are then rinsed with distilled water, dried for 48 hours, and packed in plastic bags after being submerged in a 2 percent NaOH solution at room temperature for 24 hours. Chemically modified oil palm mesocarp fibres are referred as T , and untreated fibres are referred to as U, where TM represents treated (T) oil palm mesocarp fibre (M) and UM represents untreated (U) oil palm mesocarp fibres (M), 05, 10, 15% are the weight of oil palm mesocarp fibres, and 12mm is chopped length of fiber respectively.

Table 1. Different composition to preparing the composites

Name of the sample	Fiber	% Weight fiber	Weight % matrix	Length of the fiber	Chemical treatment
TM1205	Oil palm mesocarp fiber	05	95	12mm	Alkaline treated
TM1210		10	90		
TM1215		15	85		
UM1205		05	95		Un treated
UM1210		10	90		
UM1215		15	85		

2.3. Fabrication of the composites

The required amounts of KGG powder and glycerol weighed separately, then mixed in distilled water (2.5 times weight of KGG powder) and stirred continuously in a water bath for 40 minutes to achieve a homogenous suspension. Following 20 min of stirring process, the required quantity of 1M HCL and 1 M NaOH solution was added to the pure KGG suspension to achieve the requisite pH of

8. pH-papers was used to keep track of the solution's pH (sri Aditya chemicals, Warangal, India). To enhance the tensile characteristics and thermal stability of the composite, various amounts of glutaraldehyde were added as a crosslinking agent. Glycerol was added in various quantities to minimise the brittleness of the resin laminate.

The different weight percentages (05, 10, and 15%) of oil palm mesocarp fibres (raw and treated) are combined with KGG matrix on a random orientation procedure in the second stage, then poured into glass moulds to produce composites and etc to cure for 24 hours at ambient temperature. Later, the lamina was detached from the glass mould, and test specimens were made in accordance with ASTM guidelines.

2.4. Mechanical characteristics of the composites

Universal Tensile Testing Machine (UTM), the composites' tensile, flexural, and impact properties were assessed (KITS,Warangal). In order to prepare samples for testing, they were kept in a humidity chamber for at least twenty-four hours at a temperature of 25 °C and a relative humidity level of 70%. According to ASTM standard D790, three-point flexural tests were conducted. Composite samples were divided into pieces measuring 150 mm x 12.7 mm in flexural test, speed 2mm/min. For the tensile testing specimens are Dog-bone-shaped with measurements of ASTM standard D638 is 165 mm x19 mm x13 mm. The impact strength of composite is assessed using the Izod test without a notch. According to ASTM standard D-256, impact samples 63.7 mm x 12.7 mm x 3 mm. In each test at least five samples were taken to conduct the characteristics of Impact, flexural and tensile.

2.5. Dielectric analysis

For dielectric measurements, square-shaped samples 20 mm length to cut from the composites. Specimens were sandwiched between two aluminium foils to create a parallel plate capacitor. A 6500 series precision Impedence analyzer (Wayne kerr) was used to determine the dielectric loss, dielectric constant, and dissipation factor of the specimens frequency range 100Hz to 1MHz.

3. Results and Discussion

3.1. Tensile Parameters

3.1.1. Tensile strength

Figures 1 and 2 show the tensile characteristics of the bio composites. Oil palm mesocarp fibre content increased from 0 to 10 wt percent, and overall, this resulted in a significant increase in tensile strength from 0.25 to 1.54 MPa (p 0.05). In contrast, the modulus of elasticity at break decreased overall, with the exception of the composites containing 10 wt percent fibres. Interfacial adhesion and fibre dispersion in the matrix are two elements impact on the mechanical properties of composites reinforced with fibres. As a result of the modification, more hydroxyl groups were visible on the oil palm mesocarp fibres' surface, which also enhanced the interactions with the Kondagogum matrix. The tensile strength was altered by increasing the fibre to matrix (KGG) ratio. As shown in Figures 1 and 2, composites with a 90/10 fibre to KGG matrix ratio were stronger than other composites.

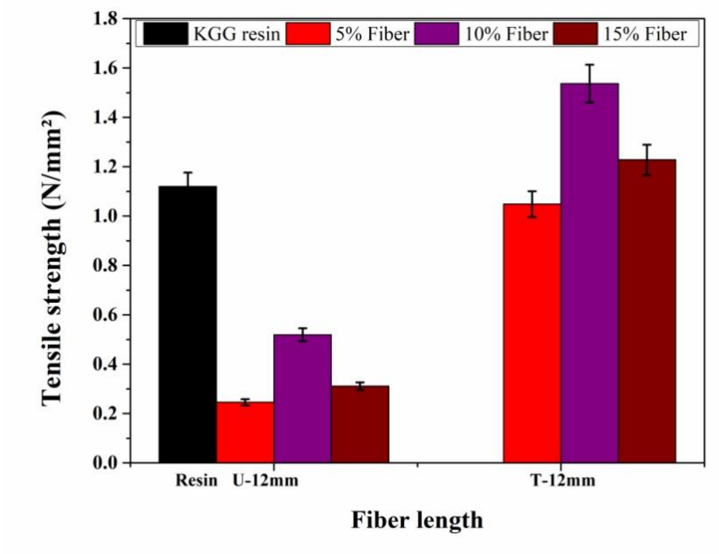

Fig. 1. Tensile strength of OPM fiber/KGG composites.

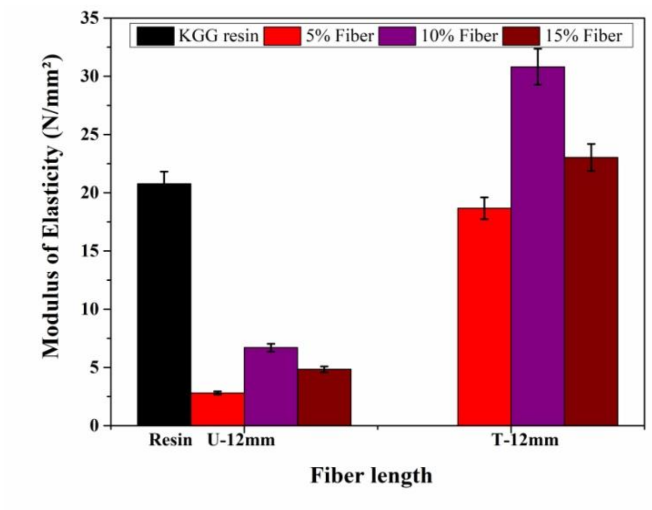

Fig. 2. Modulus of Elasticity of OPM fiber/KGG composites.

As the quantity of fibre increased, air holes became more prevalent, the tensile strength and elastic modulus is dropped. The binding between the matrix and fibres will be better in composites with a greater matrix KGG level, which will result in stronger materials. It is investigated several researchers. Mesocarp fibres from the oil palm have been utilised to create composites in the past for a variety of purposes [15]. Biocomposites were created by combining surface-treated oil palm mesocarp fibres with KGG. The modulus and tensile strength of the surface-treated composite were modified from 18.67 MPa to 30.82 MPa and 1.05 to 1.54 MPa, respectively. Untreated tensile strengths are changed from 0.25 to 0.52 MPa; Modulus is 2.81 to 6.71 MPa. Tensile strength of neat Resin : 1.12 MPa; Modulus is: 20.78 MPa. The treated OPMF/KGG composites are better properties than untreated one. In this research tensile characteristics are being similar to the Citric acid and processed oil palm empty fruit bunch fibres are combined to create starch-based bioplastic composites developed previously [33], despite the fact that the various compositions, preparation methods, and testing parameters make it difficult to compare properties of composites.

3.1.2. Flexural characteristics

Figures 3 and 4 show the flexural characteristics of the bio composites. Flexural strength has generally improved dramatically from 0.42 to 1.16 MPa. The flexural strengths and modulus drop as the fibre content rises from 0 to 15 weight percent (p 0.05), whereas the flexural modulus at break remains same, with the exception of the composite with fibre content of 05 weight percent. Interfacial adhesion and fibre dispersion in the matrix are two variables that affect the flexural characteristics of composites reinforced with fibres. The modification of oil palm mesocarp fibres resulted in more hydroxyl groups being exposed on their surface, which also improved interactions with Kondagogu gum matrix. Composites with a KGG matrix and a 95/05 fibre ratio were stronger than other composites (Figs. 3 and 4). Fiber content increased the flexural strength & flexural modulus is decreased due to load is not transferred properly (matrix cracking, fiber cracks and air gaps). The alkali treated composites are varied from 0.70 to 1.16 MPa; modulus changed from 46.47 to 87.39 MPa. Untreated flexural strengths are 0.42 to 0.69 MPa; Modulus is 18.20 to 42.14 MPa. Neat resin flexural strength : 1.04 MPa; Modulus is: 69.26 MPa. Compared to clean and untreated composites, alkali-treated composites have increased flexural strength and modulus.

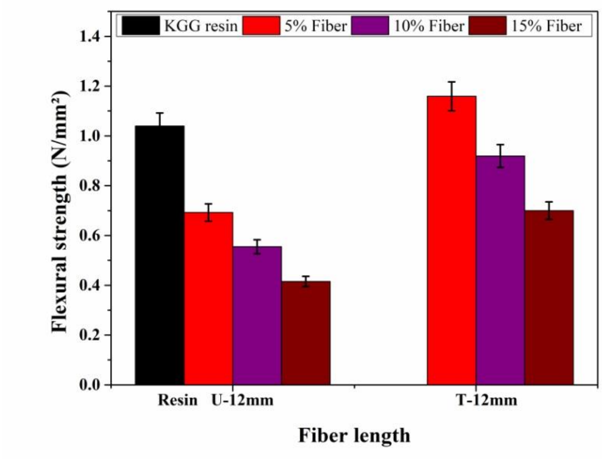

Fig. 3. Flexural strength of OPM fiber/KGG composites.

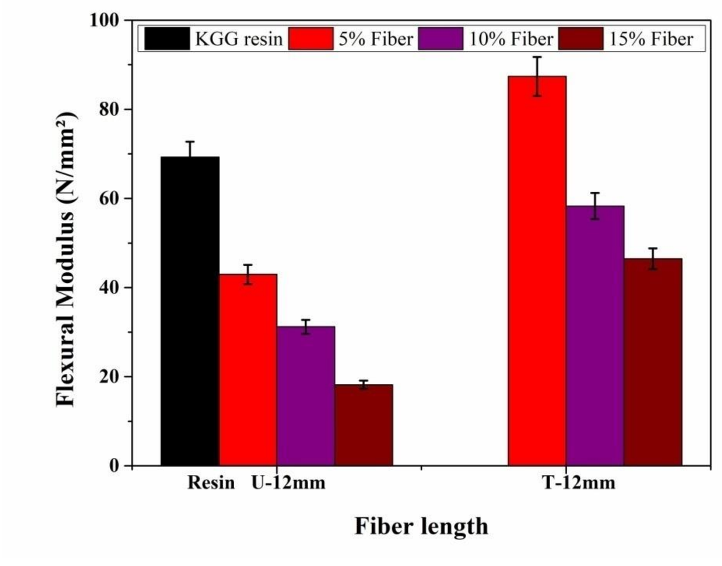

Fig. 4. Flexural modulus of OPM fiber/KGG composites.

Table 2. Mechanical Characteristics of OPM fiber/KGG Composites

Name of the sample	Tensile Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	Flexural Strength (N/mm^2)	Flexural Modulus (N/mm^2)	Impact Strength (J/m^2)
Neat KGG Resin	1.12	20.78	1.04	69.26	356.12
TM1205	1.05	18.67	1.16	87.39	884.26
TM1210	1.54	30.82	0.92	58.29	451.85
TM1215	1.23	23.04	0.70	46.47	341.20
UM1205	0.25	2.81	0.69	42.94	483.80
UM1210	0.52	6.71	0.55	31.19	448.61
UM1215	0.31	4.85	0.42	18.20	294.44

3.1.3. Impact Strength

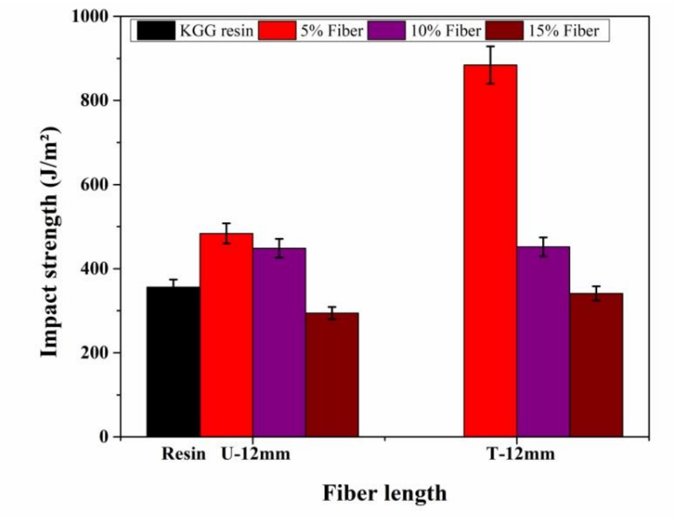

Fig. 5. Impact strength of OPM fiber/KGG composites

Table 2 provides information on the composites' Izod impact strength. The impact strength of 10 (90/10) and 15% (85/15) OPM fiber-reinforced composites reduced in comparison with neat KGG, as was the case for 5 wt percent, respectively. Numerous academic works have already illustrated how adding natural fibres to matrix alone reduces their impact strength. The impact strength decreased more rapidly as the amount of reinforcing fibre increased. The evolution of impact strength with respect to the fiber loading in Fig 8. The trend clearly demonstrates a decrease in impact strength with increasing fibre loading condition as compared to pristine KGG. The highest impact strength is 884.26 J/m^2 and lowest is 294.44 J/m^2. The treated impact strengths are varied from 341.20 to 884.26 J/m2; untreated composites: 294.44 to 483.8 J/m^2; Neat KGG matrix: 356.12 J/m^2. It can compared to neat KGG with treated composites, the losses measured in impact strength at 5 wt% fiber loading condition: 148.30%; , 10 wt% fiber loading condition : 26.88%, and Similarly in untreated composites compared to the neat resin, the impact losses occurred at 5wt% fiber loading condition :35.85%, 10 wt% fiber loading condition : 25.97% respectively. A decrease in the impact strength can be observed when the fiber load increases. For example the treated 5wt.%, the impact strength of composite range is 884.26 J/m^2, representing a decrease of 95.69% and 159.16% compared to impact strength for the fiber loading 10 wt% (451.85 J/m^2) and 15wt% (341.20 J/m^2). The presence of fibres reduces the

strength of composites by widening the loading zone that surrounds the composite's component particles. Decohesion between the fibres and matrix under loading can be used to explain these findings. As a result of this decohesion, the sample breaks more quickly due to a buildup of stress.

3.2. Dielectric Properties

3.2.1. Dielectric constant

The polarizability of a material's molecules determines its dielectric constant. The polarizability of non-polar molecules is caused by electronic and atomic polarisation, although orientation polarisation also plays a role in the polarizability of polar molecules.

Figure 1 shows the variation in dielectric constant with the increase in the frequency, with the dielectric constant decreasing with increasing frequency and reaching its lowest point at 1MHz. At high frequencies, decrease in orientation polarisation causes the dielectric constant to drop, although at lower frequencies, the full orientation of the molecule is possible, whereas at medium frequencies, the orientation is only given for a brief time. At high frequencies, molecular orientation is not possible [31].

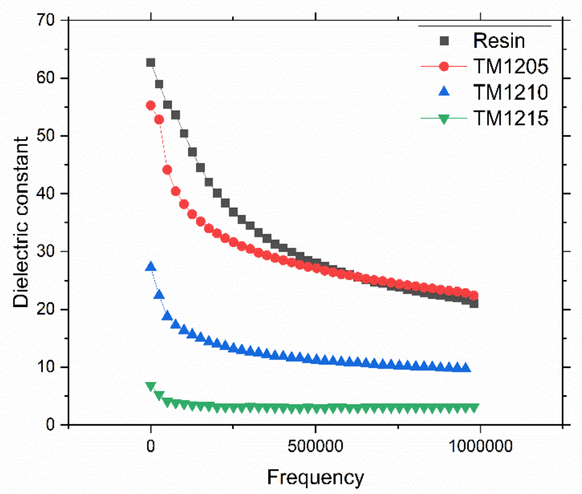

Fig. 5. Variation of Dielectric constant with respect to the increase in the frequency of treated oil palm fiber reinforced Gum Kondagogu composite.

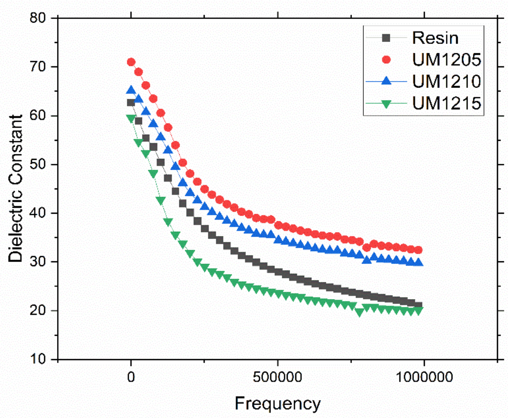

Fig. 6. Variation of dielectric constant with respect to frequency of untreated oil palm fiber reinforced Gum Kondagogu composite.

The effect of chemical modification on oil palm mesocarp fibre is shown in Figures 1 and 2. The dielectric constant decreases with increasing frequency which is due to the decrease in orientation polarisation, and the dielectric constant of a treated oil palm mesocarp fibre composite is better than the dielectric constant of an untreated oil palm fibre composite. This is caused by a loss in orientation polarisation in composites made of fibre that has undergone chemical treatment. Chemical treatment decreases the fiber's capacity to absorb water because water molecules no longer interact as well with the polar -OH groups of the fibre. Resulting in decreased orientation polarisation. Among all the treated composites, 15% fiber weight composite has low dielectric constant as compared to resin and untreated composites. The maximum value of 6.87 dielectric constant is observed at 100Hz frequency and minimum value of 3.14 at 1MHz frequency for 15% treated oil palm composite. For untreated 15% oil palm composite, minimum dielectric constant value of 20.129 is observed which is 84.40% higher than the treated fiber composites. Composite with 15% of treated oil palm fiber has the best available dielectric constant value of 3.14 which is the low among treated, untreated fiber composites and Gum Kondagogu resin.

3.2.2. Dissipation Factor

The dissipation factor is the proportion of stored energy to dissipated energy, during every cycle. It is the amount of energy lost during the reversal of electric polarization, and it is used to determine the kind and quality of electrical insulating materials and systems. It evaluates the inefficiency of insulating materials and the amount of alternating current converted to heat, which raises the temperature of the insulator and promotes its aging [31].

The influence of frequency on the dissipation factor is seen in Figures 3 and 4. The dissipation factor reduces as the frequency rises, which is owing to charge carriers and dipoles being unable to travel freely through the material at higher frequencies. The dissipation factor of chemically treated composites is likewise smaller than that of untreated composites, owing to an increase in the relaxation magnitude. Furthermore, as the frequency and percentage of fibre in the composites rises, the dissipation factor of treated composites falls, but the dissipation factor of untreated composites increases. Composites with 15% of Treated oil palm fiber has least dissipation factor among the treated fiber composites and resin with a maximum value of 0.8 at 100Hz frequency and minimum dissipation factor value of 0.2267 at 1MHz frequency. Composite with 15% of untreated oil palm mesocarp has the minimum dissipation factor of 12.57 among untreated fiber composites. Composite with 15% of treated oil palm fiber has the best available dissipation factor value of 0.2267 which is the least among treated, untreated fiber composites and Gum Kondagogu resin.

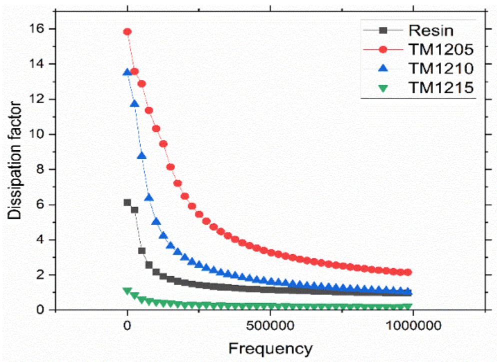

Fig. 7. Variation of dissipation factor with respect to frequency of treated oil palm mesocarp fiber reinforced Gum Kondagogu composite.

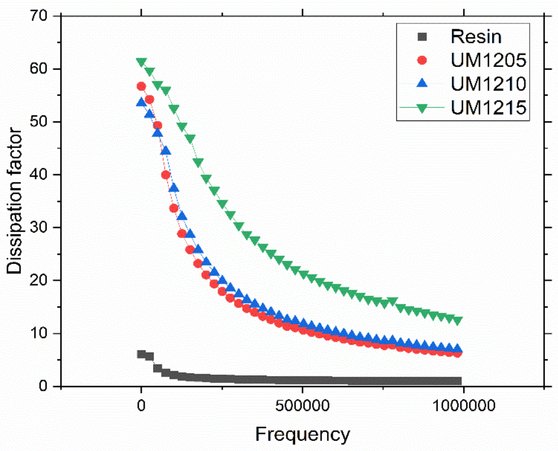

Fig.8. Variation of dissipation factor with respect to frequency of untreated oil palm mesocarp fiber reinforced Gum Kondagogu composite.

3.2.3. Dielectric loss

The energy lost in heating a dielectric substance in a variety of electric domains is known as dielectric loss. In manufacturing, dielectric losses are employed in heating applications. Figures 5 and 6 show the dielectric losses of treated and untreated fibre composites, demonstrating that treated fibre composites have lower dielectric losses than untreated fibre composites, and that dielectric loss decreases with increasing frequency and percentage of fibre weight due to a reduction in the dielectric constant & polarisation mechanism's relaxation or resonance frequencies. Composites with 15% of Treated oil palm mesocarp fiber fiber has least dielectric loss among the treated fiber composites and resin with a maximum value of 4.56 at 100Hz frequency and minimum value of 0.588538 at 1MHz frequency, Composite with 5% of untreated oil palm mesocarp fiber has the minimum dielectric loss of 49.129. Composite with 15% of treated oil palm fiber has the best available dielectric loss value of 4.56 which is the least among treated, untreated fiber composites and Gum Kondagogu resin.

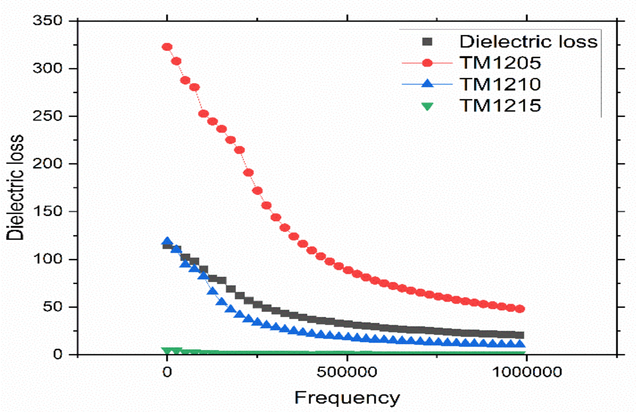

Fig.9. Variation of dielectric loss with respect to frequency of treated oil palm mesocarp fiber reinforced Gum Kondagogu composite.

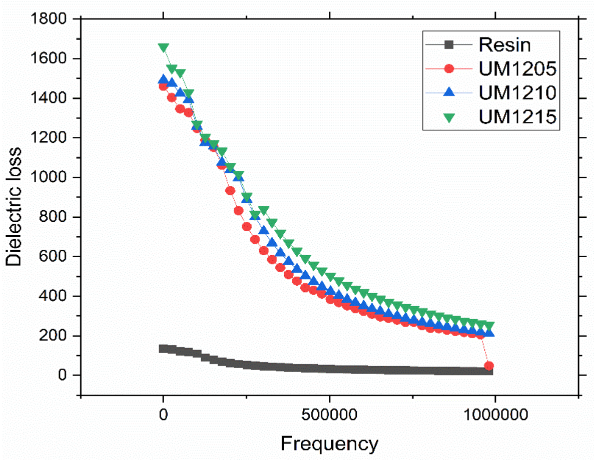

Fig.10. Variation of dielectric loss with respect to frequency of untreated oil palm mesocarp fiber reinforced Gum Kondagogu composite.

4. Conclusions

In this article, the different composites are created utilising a hand layup procedure with random orientation, Kondagogu gum as the matrix, and oil pal mesocarp fibre as the reinforcement material. The characteristics of the created composites in comparison to treated and untreated Composites have been thoroughly investigated. All treated composites had greater tensile strength and modulus than untreated composites, demonstrating that KGG resin offers sufficient bonding with the fibres. When compared to untreated and raw KGG resin, sample treated 10 weight percent composites showed the highest level of tensile strength. All treated composites have greater flexural strength and modulus than untreated composites. The flexural strength of the composites is mostly determined by the KGG matrix content, and treated 05 weight percent OPM fibre is found to have higher strength than untreated of all weight percentages of the composites. When the fibre content is raised, the flexural strength declines. According to impact studies, the force used to pull fibres out of the matrix determines the strength of the impact. Compared to composites with 10 and 15 weight percent fibre content, the impact strength is higher at 5 weight percent composites. The impact strength of the OPMF/KGG composites is observed to decrease after 05 percent OPM fibre, with better results found at this level. For treated and untreated fibre composites of various fibre contents(5 percent , 10 percent , 15 percent) dielectric metrics such as dielectric constant, dielectric loss, and dissipation factor were evaluated from 100Hz to 1MHz. If increased frequency and % fiber weight, dielectric constant and dissipation factor decreased, which is due to an increase in the orientation polarisation of the polar groups contained in lignocellulosic fibres. Chemical treatment reduced the dielectric constant, dissipation factor, and dielectric loss of fibre. The composites created in this work are appropriate for a wide range of electronic applications due to their dielectric properties. Gum Kondagogu and oil palm mesocarp fibre composites with a dielectric constant range of 3.14 to 6.87 have an ability to the dielectric materials like Mica, glass, durite and formica and reduce e-waste and improve the environmental friendliness of electronic items.

Nomenclatures

Abbreviations

OPMF Oil palm mesocarp fiber

KGG	Kondagogu Gum
TM	Treated oil palm mesocarp fiber composites
UM	Untreated oil palm mesocarp fiber composites
UTM	Universal testing machine
ASTM	American Society for Testing and Materials

References

1. Al-Maharma, A.Y.; Sandeep, P.P.; and Markert, B. (2022). Environmental impact analysis of plant fibers and their composites relative to their synthetic counterparts based on life cycle assessment approach. Rangappa, S.M.; Puttegowda, M.; Parameswaranpillai, J.; Siengchin, S.; and Gorbatyuk, S. (eds). *Advances in Bio-Based Fiber*, Woodhead Publishing, United Kingdom, 741-781.
2. Mayilswamy, N.; and Kandasubramanian, B. (2022). Green composites prepared from soy protein, polylactic acid (PLA), starch, cellulose, chitin: a review. *emergent materials*.
3. Bhuvaneswari, H.B.; Vinayaka, D.L.; Ilangovan, M.; and Reddy, N. (2017). Completely biodegradable banana fiber-wheat gluten composites for dielectric applications. *Journal of Materials Science: Materials in Electronics*, 28, 12383–12390.
4. Sashidhar, R.B.; Raju, D.; and Karuna, R. (2015). Tree Gum: Gum Kondagogu. In: Ramawat, K., Mérillon, JM. (eds) *Polysaccharides*. Springer, Cham, 185-217.
5. Prasad, N.; Thombare, N.K.; Sharma, S.C.; and Kumar, S. (2022). Production, processing, properties and applications of karaya (Sterculia species) gum. *Industrial Crops and Products*, 177, 114467.
6. Rahman, S.; Konwar, A.; Majumdar, G.; and Chowdhury, D. (2021). Guar gum-chitosan composite film as excellent material for packaging application. *Carbohydrate Polymer Technologies and Applications*, 2, 100158.
7. Kiruthika, A.V.; Priyadarzini, T.R.K.; and Veluraja, K. (2012). Preparation, properties and application of tamarind seed gum reinforced banana fibre composite materials. *Fibers Polymers* 13, 51–56.
8. Vinayagamoorthy, R.; and Venkatakoteswararao, G. (2021). Development and Characterization of Bio-Composites Using Senegalia Catechu Resin. *Polymers and Polymer Composites*, 29(9), S1268–S1279.
9. Silva-Guzmán, J.A.; Anda, R.R.; Fuentes-Talavera, F.J.; González, R.M.; and Lomelí-Ramírez, M.G. (2018). Properties of Thermoplastic Corn Starch Based Green Composites Reinforced with Barley (Hordeum vulgare L.) Straw Particles Obtained by Thermal Compression. *Fibers Polymers*, 19(9), 1970–1979.
10. Sunny, T.; Pickering, K.L.; and Lim, S.H. (2020). Alkali treatment of hemp fibres for the production of aligned hemp fibre mats for composite reinforcement. *Cellulose* 27(5), 2569–2582.
11. Islam, M.H.; Islam, M.R.; Dulal, M.; Afroj, S.; and Karim, N. (2022). The effect of surface treatments and graphene-based modifications on mechanical properties of natural jute fiber composites: A review. *iScience*, 25(1), 103597.
12. Behera, S.; Gautam, R.K.; and Mohan, S. (2022). Study of Mechanical Properties of Chemically Treated Kenaf Fiber and Its Composites. In: Prasad, R.; Sahu, R.; Sahoo, K.L.; and Jadhav, G.N. (eds) *Advancement in Materials Processing Technology*. Springer Proceedings in Materials, Springer, Singapore, 12, 115-123.
13. Wang, B.; Yan, L.; and Kasal, B. (2022). A review of coir fibre and coir fibre reinforced cement-based composite materials (2000–2021). *Journal of Cleaner Production*, 338, 130676.

14. Mansingh, B.B.; Binoj, J.S.; Sai, N.M.; Hassan, S.A.; Siengchin, S.; Sanjay, M.R.; Liu, Y.C. (2021). Sustainable development in utilization of Tamarindus indica L. and its by-products in industries: A review. *Current Research in Green and Sustainable Chemistry*, 4,100207.
15. Asyraf, M.R.M.; Ishak, M.R.; Syamsir, A.; Nurazzi, N.M.; Sabaruddin, F.A.; Shazleen, S.S.; Norrrahim, M.N.F.; Rafidah, M.; Ilyas, R.A.; Rashid, M.Z.D.; and Razman, M.R. (2022). Mechanical properties of oil palm fibre-reinforced polymer composites: a review. *Journal of Materials Research and Technology*, 17, 33-65.
16. Sivaranjana, P.; and Arumugaprabu, V. (2021). A brief review on mechanical and thermal properties of banana fiber based hybrid composites. *SN Applied Sciences*, 3, 176.
17. Gao, X.; Zhu, D.; Fan, S.; Rahman, M.Z.; Guo, S.; and Chen, F. (2022). Structural and mechanical properties of bamboo fiber bundle and fiber/bundle reinforced composites: a review. *Journal of Materials Research and Technology*,19, 1162-1190.
18. Arebelaiz A.; Fernadez, B.; Cantero, G.; LanoPonte, R.; Vlela, A.; and Monfragon, I. (2003). Mechanical properties of flax fibre/ polypropylene composites. Influence of fibre/matrix modification and glass fibre hybridization. *Composites Part A: Applied Science and Manufacturing*, 36 (12), 1637–1644.
19. Peças, P.; Carvalho, H.; Salman, H.; and Leite, M. (2018). Natural Fibre Composites and Their Applications: A Review. *Journal of Composites Science*, 2(4), 66.
20. Wang, W.; Sain, M.; and Cooper, P.A. (2006). Study of moisture absorption in natural fiber plastic composites. *Composites Science and Technology*, 66 (3-4), 379–386.
21. Hao, H. (2013). A review on the dielectric materials for high energy-storage application. *Journal of Advanced Dielectrics*, 3, 1.
22. Gupta, T. (2009). Diffusion and Barrier Layers. In: *Copper Interconnect Technology*. Springer, New York, NY, 111-159.
23. Maex, K.; Baklanov, M.R.; Shamiryan, D.; Brongersma, S.H.; and Yanovitskaya, Z.S. (2003). Low dielectric constant materials for microelectronics. *Journal of Applied Physics*, 93, 879.
24. Ben Amor, I.; Arous, M.; and Kallel, A. (2014). Effect of maleic anhydride on dielectric properties of natural fiber composite. *Journal of Electrostatics*, 72 (2), 156-160.
25. Jayamani, E.; Hamdan, S.; Rahman, M.R.; and Bakri, M.K.B. (2014). Comparative Study of Dielectric Properties of Hybrid Natural Fiber Composites. *Procedia Engineering*, 97, 536-544.
26. Singh, J.; and Singh, B. (2013). Gum Kondagogu- A Natural Exudate from Cochlospermum gossypium. *Botanica*, 62, 115-123.
27. Patel, J.P.; and Parsania, P.H. (2018). Characterization, testing, and reinforcing materials of biodegradable composites. Shimpi, N.G. (ed.). In: Woodhead Publishing Series in Composites Science and Engineering, *Biodegradable and Biocompatible Polymer Composites*, Woodhead Publishing, Cambridge, 55-79.
28. Bhuvaneshwari, H.B.; and Reddy, N. (2018). A review on dielectric properties of biofiber based composites. *Advanced Composites and Hybrid Materials* , 1 (4), 635–648.
29. Mishra, S.C.; and AIreddy, H. (2010). Evaluation of dielectric behaviour of bio-waste reinforced polymer composites. *Journal of Reinforced Plastics and Composites*, 30(2), 134-141.
30. Chand, N.; and Jain, D. (2005). Effect of sisal fibre orientation on electrical properties of sisal fibre reinforced epoxy composites. *Composites Part A: Applied Science and Manufacturing*, 36 (5), 594-602.
31. Jacob, M., Varughese, K.T.; and Thomas, S. (2006). Dielectric characteristics of sisal–oil palm hybrid biofibre reinforced natural rubber biocomposites. *Journal of Materials Science*, 41 (18), 5538–5547.

32. Ahmad, M.H.; and Nurazuwa, M.N. (2008). Mix design of palm oil fiber concrete. In: *International Conference on Civil Engineering (ICCE08).* Pahang: Universiti tun Hussein on Malaysia, 2008.
33. Yang, J.; Ching, Y.C.; Chuah, C.H.; Hai, N.D.; Singh, R.; and Nor, A.R.M. (2021). Preparation and characterization of starch-based bioplastic composites with treated oil palm empty fruit bunch fibers and citric acid. *Cellulose*, 28, 4191–4210.